Coping with unreliability in public transport chains

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Abstract

Unreliability in public transport means that actual departure and arrival times may deviate from the official timetable. Data on unreliability are usually uni-modal. In this paper we address unreliability from a multimodal perspective, implying a shift of attention away from the supplier towards the customer. Estimates of unreliability of public transport chains in the Netherlands are provided. In addition, customer valuation of unreliability is estimated. We find that the valuation of a certain travel time loss of 1 minute is 27 cents, whereas the valuation of a 50% probability of a 2 minute delay is **64** cents. This implies a strong attitude of risk aversion towards travel time of passengers. On the basis of these values an evaluation of probability enhancing strategies has been carried out. We conclude that among the most promising means of improving the overall quality of the chains is that travellers use the bicycle as an entrance or exit mode. Other measures which are relatively inexpensive to implement and result in fairly large gains for the average public transport passenger, are an increase in transfer times and a strict constraint on bus drivers to prevent them from departing early.

Contents

1 Introduction

Unreliability is a major problem in both private and public transport in many countries. In private transport a major cause of unreliability is congestion on roads, which can be further broken down into recurrent and non-recurrent congestion. Recurrent congestion occurs every weekday at particular times and places and leads to an increase in total travel time. For regular road users recurrent congestion basically does not lead to issues of unreliability or uncertainty; they just know that a trip which normally takes 30 minutes requires 15 extra minutes. The opposite case is that of non-recurrent congestion. Unpredictable incidents of various kinds can lead to a gridlock situation which not only leads to an increase of average travel time but also to a large variance, and hence to unreliability. In terms of average delays, recurrent congestion seems to be more important than non-recurrent congestion in private transport.

In public transport the balance between recurrent (predictable) and non-recurrent (non-predictable) delays tends to differ when compared with the situation in road transport. Here the unpredictable component tends to be larger, the reason being that public transport operators normally utilise timetables for their services. If we assume that operators try to design realistic timetables, they will adjust the tables whenever there are frequent delays. Thus, one would expect that especially travellers using public transport encounter delays that could differ day by day.

There is yet another reason why the variability of travel time in public transport may be a special cause for concern. Many public transport travellers travel via a chain with more than one element, therefore the problem becomes acute if connections are missed. Especially in the case of low frequencies, a delay of 5 minutes in the first part of a chain may mean that a connection is missed and the delay jumps to 30 minutes. This problem is especially severe when different transport operators are involved in various parts of a chain. It is remarkable that the issue of reliability in public transport has received scant attention in the literature, and that the reliability of public transport chains in particular has not been studied in a systematic way.

An implication of the consideration of reliability of public transport *chains* is that attention shifts away from the input side (reliability of vehicle arrival times) towards the output side (reliability of passenger arrival times). The difference between the two is small in the case of chains with only one element', but is substantial in the case of chains with more than one element due to the problem of missed connections. Our approach to the analysis of unreliability in the context of chains is therefore in agreement with a customer-oriented analysis of public transport services. It considers the issue of reliability of public transport from a *consumer* rather than a *producer* perspective.

The aim of the present paper is to analyse the reliability of public transport chains with special emphasis on alternative strategies of public transport operators for improving reliability. After a short literature review in section 2, we discuss methods for estimating distributions of travel and/or arrival times (section 3). Simulation results for the chains are given in section 4. Various strategies of public transport operators and travellers of coping with the unreliability problem are covered in section 5. Section 6 contains an evaluation of these strategies. Section 7 concludes. The paper will not focus on statistical/technical aspects of reliability; instead we will concentrate on the policy implications of our analysis.

2 Review

The reliability of public transport for a certain trip can be defined in terms of the difference between the distribution of actual travel times for the trip and its scheduled travel time. This definition can be refined by identifying the distributions under various external conditions (e.g., work day versus weekend, normal weather versus extreme weather conditions). Such a definition in objective terms should be clearly discerned from subjective perceptions of travel times, where (potential) travellers may perceive the scheduled travel time and its actual distribution under various circumstances which are rather far removed from the real situation. Rooijers (1998) finds that the perceptions of non-users of public transport on its reliability are lower than those of regular users.

Public transport companies generally inform travellers about the *scheduled* travel times (for example, by the distribution of timetables, telephonic route advice and route information via the Internet). An additional policy is to give warnings about current and foreseeable future delays (for example, large delays in the case of track reconstruction). The information on the distribution of *actual* travel times is usually provided at a very aggregate level (see, for example table 1[2]) so that it is of no use to travellers who need to know the variance of travel times on particular routes.

Table 1 Reliability of train services in selected European countries (probability in % that the train arrives at the destination with a delay of less than 5 minutes, 1993).

Country	Intercity	Other trains
The Netherlands	91.3	97.1
Germany	82.3	93.6
France*	81.1	93.4
United Kingdom**	90.6	92.0

* less than 3 minutes
** less than 10 minutes
Source: Ministry of Transport (1996)

In public transport the issue of reliability is closely related to that of timetable construction. As noted by Ceder (1986), timetable construction has received scarce attention in the literature on public transport operations. One of the obvious trade-offs with which one must deal when timetables are constructed is that faster transport or shorter halting times will improve the scheduled travel times, but will have an adverse effect on the reliability of the service (see, Powell and Sheffi, 1983, Hall, 1985, Bookbinder and Ahlin, 1990, Carey, 1994). Hallowell and Parker (1998) give a related analysis in the field of freight transport.

A problem addressed by Carey (1998) is that to improve reliability of services, public transport firms usually allow for some extra time for parts of trips within a schedule. However, when more time is allocated for these sections of trips, the trip often tends to take longer due to the behavioural response of drivers. Therefore, the actual gain in reliability may be smaller than the anticipated gain. Carey notes that this aspect has to be taken into account when developing optimal time schedules.

A related field where reliability is important concerns the choice of shapes of transport networks (for example, hub-and-spoke networks versus fully-connected networks). Hub-and-spoke networks lead to advantages in terms of economies of scale and frequencies, but they can only function properly when measures have been taken to ensure reliability in the hub; otherwise too many travellers might miss the connection in the hub.

Reliability can be measured in a number of ways. A common measure is the one presented in table 1: the probability p that a vehicle arrives x minutes late. There are several other definitions, each focuses on a particular aspect of the distribution of departure or arrival times:

- the probability of an early departure;
- the mean difference between the expected arrival time and the scheduled arrival time;
- the mean delay of an arrival given that one arrives late;
- the mean delay of an arrival given that one arrives more than x minutes late;
- the standard deviation of arrival times;
- adjusted standard deviation of arrival times (ignoring the early arrivals), and various other more complex measures to represent the seriousness of unreliability.

Another approach to the measurement of reliability is a formulation in cost terms. This has the advantage that it can be included within an analysis of optimal timetables where costs of scheduled travel time on links and waiting time at stops must be traded-off against costs of unreliability. The unreliability related costs can be measured as the costs of arriving later or earlier than scheduled at a stop, and the costs of departing later or earlier than scheduled at a stop (see, for example Carey, 1994). A relevant distinction here is the difference between the costs of the *public transport company* and those of the *traveller*. Both perspectives are important when one wants to arrive at optimal timetables.

3 Outline of research approach

In the remainder of the paper we carry out an empirical analysis of unreliability of public transport services in the Netherlands. Our approach can be outlined as follows:

1. Analysis of unreliability of public transport services for each transport mode (train, tram, urban bus, interurban bus, etc.). This leads to the *estimation of density functions of departure and (conditional) arrival times* based on data provided by specific public transport operators in the Netherlands;
2. Drawing of a representative *sample of public transport chains* of Dutch citizens;
3. *Computation of the scheduled arrival time* of the chains drawn in 2;
4. *Simulation of realisations* of the chains based on the distributions given in 1;
5. *Computation of various measures of unreliability* of chains based on the simulation results in 4;
6. Formulation of a number of *reliability enhancing strategies* of public transport service providers and travellers;
7. *Simulation of the implications of the alternative strategies* in 6 on reliability, travel time and waiting time;
8. *Evaluation of these strategies* based on the valuation by travellers of reliability, travel time and waiting time.

A detailed account of the various steps is given in Bruinsma et al. (1998). In this paper we will give a short account of steps l-5 in section 4. Sections 5 and 6 contain a more detailed discussion of the final three steps.

4 Estimating unreliability in public transport chains

The first five steps of our approach have been conducted as follows:

*Step 1: Analysis of unreliability of public transport services for each **transport** mode separately*
Unreliability of scheduled services can be analysed in terms of the distribution of three items: departure times T_D, travel times T_R and arrival times T_A, where obviously:

$$T_A = T_D + T_R,$$

For the purpose of our study we need distributions of departure times and arrival times. The data inputs for several transport modes are available in a rather aggregate way. For example, for interurban buses, the distribution is published in a form similar to table 2. One striking feature is that buses often arrive and depart early compared with the scheduled times.

The data collected by the public transport operators differs by the number of routes, observation points and time period (year, season, period of the day) for which the data was collected. Tables 3 and 4 give full information on the quantity and quality of the data used in our data base.

Table 4 shows that for trains, trams and buses the data have been identified according to

Table 2 Available data on the distribution of arrival times (deviations of scheduled times in minutes) of interurban buses.

Ravon	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	>
Arrivals																				
Tilburg stad		1		6	3	5	6	14	31	13	4	4	5		1					
Veghel / Oss	1		2	1	5	4	9	17	22	13	6	14	4	3	2	1	1	3		2
Heusden			2		5	3	5	7	13	5	3	2	1			1	1			1
Et cetera																				
Departures																				
Tilburg stad	1	3		2	1	5	13	31	70	31	18	13	3	6	2	4	1	1		1
Veghel / Oss				1			1	10	80	29	27	10	12	6	9	2		2	1	2
Heusden			1		1	4	8	8	26	23	12	3		1		1	1			1
Et cetera																				

Source: BBA

Table 3 Data used on departure and arrival times in public transport

	What is measured	Period	Observation points
Urban bus / tram	3 lines in Amsterdam	Winter 1996	Intermediate stops
Metro	1 line in Rotterdam	2 days Sept. 1982	2 intermediate stops
Interurban bus	All lines in Brabant	Sept.-Oct. 1996	Selection of 41 stops
Stopping train / intercity	9 rail lines	2 weeks March 1997	All stations
Stopping train / intercity	9 rail lines	4 Sundays March 1997	All stations

Table 4 Number of observations

	Peak		Off-peak		Sundays	
	Departures	Arrivals	Departures	Arrivals	Departures	Arrivals
Stopping train	7015	7036	7250	7255	2188	2185
Intercity	4217	4178	4381	4435	1685	1707
Urban bus	790		686		130	
Tram	751		559		128	
Metro	418					
Interurban bus	1471					

time of the day (peak, off-peak, Sundays), but for the other modes this distinction has not been made. A property of the data on the deviations from the scheduled time is that occasionally long time intervals are used (for example, in table 2 we have an interval of 10 minutes or longer). This makes these data difficult to use in a simulation study. Therefore, on the basis of this data, the parameters of a smooth distribution function of arrival times have to be estimated. Once these parameters are known, simulation techniques can be applied to generate values of possible realisations of the arrival time[3]. Departure and conditional arrival time distributions are usually asymmetric: public transport vehicles might depart slightly early, but the probability of late departures is usually much higher. Therefore, natural candidates for departure time distributions are the gamma, log-normal and Weibull distributions (see Dauber, 1986 and Tijms, 1994). In standard form these distributions are characterised by two parameters: the mean and the variance. However, the standard form of these distributions is such that they do not allow for negative values of departure and arrival times: early departures and early arrivals would be ruled out, which is obviously unacceptable, given the results of table 2. Therefore, a shift parameter has to be added to allow for the possibility of early arrivals and departures. Details of the estimations can be found in Bruinsma et al. (1998).

We find that all transport modes sometimes depart too early, although train and metro seldom depart over one minute early. An early departure may have more severe impacts than a late departure: passengers may miss their connections in the travel chain; in addition they are forced to arrive several minutes early at public transport stops to avoid the risk that the bus, tram or train has already departed. Not surprisingly, the metro services operate best on schedule; the interurban buses operate worst (see figure 1). The metro runs on a rather simple network and has its own separate track apart from other traffic. Interurban buses are often noted by their rather long-distance services through various traffic situations: peripheral and urban areas are within the same route. This apparently makes it difficult for bus drivers to drive according to the timetables at the intermediate stops.

The distributions presented in figure 1 relate to arrival and departure times (T_A and T_D). If one wants to know the distribution of travel times T_R, one can make use of a convolution approach based on the definition $T_R = T_A - T_D$ in conjunction with the distributions of T_A and T_D (for a discussion, we refer to Bruinsma et al., 1998).

Step 2 : Drawing of a representative sample of public transport chains of Dutch citizens

The Dutch annual travel survey (OVG) has been used to draw a random stratified sample of 300 public transport trips (stratification according to the degree of urbanisation in the respondent's residential area and according to the length of the trip).

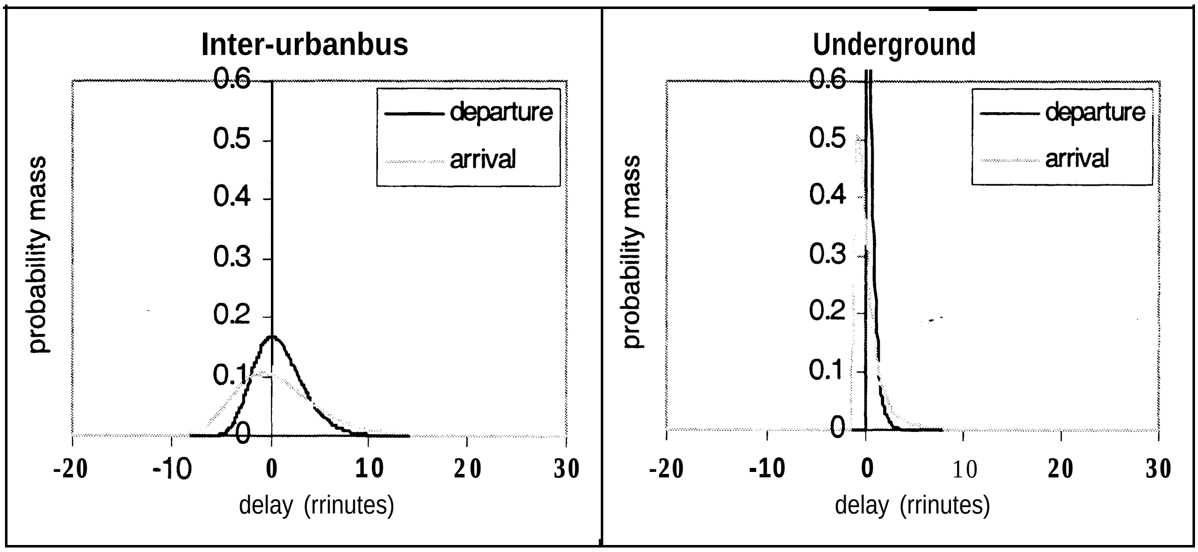

Figure 1 Estimated departure and arrival time deviations

Step 3: *Computation of the scheduled arrival time of the trips drawn in 2*

Since the travel survey is not sufficiently detailed to reveal the exact route chosen, route choice software for public transport trips has been used to reconstruct the exact route chosen. The software also provides information on service frequencies for the various elements of the transport chain which is a necessary input to the simulations later on. The scheduled travel times have been computed for three different times of the week:

- weekday, departure at circa 7.30 am;
- weekday, departure at circa 13.00 pm;
- Sunday, departure at circa 11 .OO pm.

About 70 % of the chains consist of more than one element; this underlines the importance of considering our fundamental idea that unreliability is especially important in view of the risk that one misses the connection with the next train/bus/tram.

Step 4: Simulation of realisations of the chains based on the distributions given in I

For each element in each chain, 2500 realisations have been drawn, based on the density functions estimated in step 1. These simulations have been combined to provide estimations of the actual distributions of travel times. In the event that passengers miss connections, the frequency information of step 3 is used to simulate the arrival time of the next train/bus/tram. A basic assumption underlying our simulation approach is that realisations of arrival and departure times in different trip elements are independent. We know that in reality this may not always be true. For example, we may find that drivers of buses waiting at a bus station take into account delays of buses with arriving passengers. This would obviously improve the reliability for passengers who would otherwise miss their connections. Note that the down-side is the reduction of reliability for passengers who were already in the first bus. Another aspect we do not take into account is that delays of different vehicles may not be independent from each other because of overall external conditions (extreme weather, a particular railway accident affecting a large section of the network, etc.). Thus, we conclude that the examination of interdependencies between realisations on different elements of the same chain may reveal tendencies towards an increase as well as a decrease in reliability. Were data on delays and driver strategies for coping with these delays more refined, it would be possible to develop advanced simulation approaches which incorporate these interdependencies. However, such data were unfortunately not available to us.

The results for the deviations of the actual arrival times from the scheduled times during the morning peak hour are shown in figure 2. The density is peaked around zero, but it has some additional peaks at delays of 30, 60 and 120 minutes. This obviously relates to the basic frequencies of most public transport services in the Netherlands. It is important to observe that this density function with multiple modi is quite different from the unimodal and smooth density function found for the individual elements of the chains. The--aggregation of these smooth functions in the context of chains yields a density function that is far from smooth.

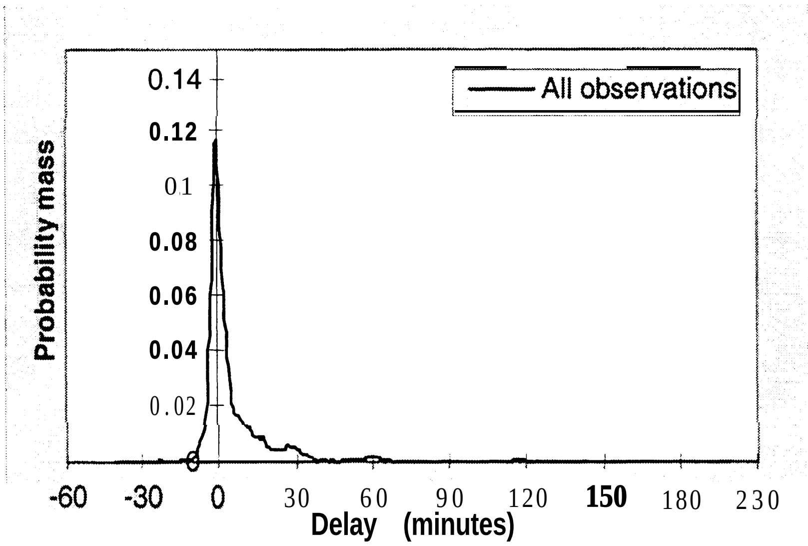

Figure 2 Distribution of deviations of arrival times for public transport chains (morning peak hour)

Table 5 Average scheduled and simulated times in the morning peak, off-peak hours and on Sundavs.

	Morning peak	off-peak	Sundays
Average scheduled travel time	59.9 min.	**61.8** min.	65.1 min.
- of which waiting time	I 5.1 min.	6.4 min.	8.7 min.
Average simulated travel time	65.9 min.	67.9 min.	72.5 min.
- of which waiting time	**10.7** min.	12.1 min.	15.4 min.
Extra travel time (simulated versus scheduled, %)	10.0 %	9.9 %	**11.4** %
Arrival at least 2 min. earlv	I **0.5** %	I **0.7** %	I 0.8 %
Arrival 0 – 2 min. early	I **30.1** %	29.6 %	**31.7** %
Arrival as scheduled	12.0 %	**11.6 %**	**12.7 %**
Delav O-5 min.	I **30.4** %	29.7 %	**31.2 %**
Delay 6-10 min.	**8.8** %	9.7 %	**6.5** %
Delav 10-30 min.	13.2 %	12.7 %	9.1 %
Delav over 30 min.	5.1 %	6.1%	8.0%

Step 5: Computation of various measures of unreliability of chains based on the simulation results in 4

In table 5 we give a number of measures of unreliability for various times of the week. We find that the average delay of public transport chains is rather small: about 6 minutes, given an average length of circa 1 hour. One reason is that a substantial part of all trips (about 30 %) arrives (slightly) early. The probability of an arrival on time or a short delay between 0 and 5 minutes is estimated at about 45 %. Delays of between 5 to 30 minutes occur in about 20 % of the cases. Extremely long delays (more than 30 minutes) occur in about 5 % of the cases.

When we compare the various times of the week, it becomes clear that although in the morning peak there is more congestion so that travel time variances are larger, the average waiting time is relatively low compared to an off-peak or Sunday trip. The reason is that the low reliability of individual trips is more than compensated for by the high frequency of services. The opposite case is the Sunday trip, where variance of service is relatively low, but frequencies are also low. This leads to a high probability of long delays (8 % for more than 30 minutes).

Another interesting aspect of the table is that the percentage of waiting time on platforms is about 10 % of the travel time when services are running according to schedule; the remaining 90 % is devoted to the ride in the transport vehicle. Unreliability leads to a distinct change in these percentages. The increase in total travel time is almost completely due to an increase in waiting times on platforms (waiting time increases to about 20 %). Thus, unreliability not only leads to an increase of total travel time, but also to the percentage of travel time which is the least comfortable: travellers prefer to sit in a vehicle rather than wait on a platform (Van der Waard, 1989).

Table 6 Average scheduled (in minutes) and average simulated (as a % of scheduled) travel times for some selected types of public transport chains

	Average scheduled travel time			average simulated travel time as a % of the scheduled travel time		
	Morning Peak	Off-Peak	Sundays	morning peak	off-peak	Sundays
Bus	28.8	28.7	28.1	100.3	102.4	101.1
bus/bus	50.5	54.5	55.2	106.1	106.4	110.9
train/bus	53.7	60.7	65.3	109.5	103.6	109.6
bus/train	58.0	55.2	64.6	108.8	109.2	102.3
bus/train/bus	74.3	71.0	85.5	111.6	111.8	110.5
all chains	59.9	61.8	65.1	110.0	109.9	111.4

Five types of public transport chains have been selected as good representatives for the diversity of chains. In table 6 the average travel times for each selected type of public transport chain are given. Columns 1-3 give the *scheduled* travel time for trips during the morning peak hour, the off-peak hours and on Sundays, respectively. Columns 4-6 show the *simulated* average travel time in relation to the scheduled travel time for that specific period of the day. This allows us to make comparisons according to the type of public transport chains and the period of the day when the trip takes place. The table shows that the period of the day has little impact on the difference between the average simulated and the scheduled travel time. The number of transfers seems however, to be more decisive: the difference between the average simulated travel time and the scheduled travel time is low (less than 2.5%) in chains without a transfer, and high (about 11 %) in chains with two transfers.

5 Effects of policies to improve the reliability of transport services

Travellers and public transport operators can take a number of-measures to improve the reliability of the chains (step 6). Important determinants of the reliability of a transport chain factors are transfer times, frequency of service, reliability of the departure time, and reliability of the arrival time.

The simulation model used in section 4 to analyse the distribution of travel (or arrival) times in the existing chains can also be used to generate the travel (arrival) times for policy measures to further improve the reliability of public transport chains (step 7). This leads to changes in the distribution of travel times and arrival times for all possible policy measures. A basic assumption underlying the simulations is that the parameters of the unimodal departure time and arrival time distributions remain unaffected. This may not always happen in reality. For example, Carey (1998) noted that when drivers have more time for certain tasks (such as driving from A to B), these tasks tend to take longer due to behavioural responses. Given the limited quality of the data available we decided not to take this aspect into account.

The list of possible alternatives we have simulated is presented in table 7. Alternatives 1-3 address the use of the bicycle in public transport chains. In the Netherlands the bicycle is an important entrance mode for train passengers: about one third of all passengers arrive by bicycle at railway stations (at the home end of the chain; see Keijer and Rietveld, 1998). From a reliability perspective, the bicycle is interesting because it is continuously available so there is no risk that a connection is missed. Concerning the speeds of bicycles we assume that:

- a trip by bicycle takes as much time as a trip by urban bus;
- a trip by bicycle takes 1.25 as much time as a trip by tram;
- a trip by bicycle takes 1.5 as much time as a trip by interurban bus;
- a trip by bicycle takes twice as much time as a trip by metro.

These figures hold true for trips that require no more than 15 minutes by bicycle: for longer trips these speed factors may change. For instance, the interurban bus becomes much faster than the bicycle on longer - peripheral – distances. In the analysis we have only considered bicycle trips of less than 15 minutes.

For variants 7-10 in table 7 (increase in transfer time and higher operating speeds of the modes), the chains have been adjusted. In this adjustment the departure time is taken as a starting point. In the following example, variant 9 (10 % increase in operating speed of interurban buses) has been reconstructed as follows:

Mode	Frequency	Departure	Arrival		Departure	Arrival
Interurban bus	30 min.	7.30	8.04	Becomes	7.30	8.01
Tram	5 min.	8.07	8.10		8.02	8.05

Table 7 List of measures intended to improve reliability of public transport

Variant	Alternative
1	Bicycle used as entrance mode when travel time by bicycle is less than 15 minutes
2	Bicycle used as exit mode when travel time by bicycle is less than 15 minutes
3	Bicycle used as entrance and/or exit mode when travel time by bicycle is less than 15 minutes
4a	Interurban buses 100 % reliable*
4b	Interurban buses 50 % reliable**
5a	Urban buses 100 % reliable*
5b	Urban buses 50 % reliable**
6a	Tram 100 % reliable*
6b	Tram 50 % reliable**
7	All train/train transfers increased to 10 minutes and all train/bus transfers and vice versa to 15 minutes
8	All travel times train decreased bv 10 %
9	All travel times interurban buses decreased by 10 %
10	All travel times decreased by 10 %
11	All frequencies at least twice an hour
12	All frequencies train at least twice an hour
13	All frequencies train at least four times an hour
14	All frequencies interurban buses at least twice an hour
15	All frequencies urban buses at least twice an hour
16	All frequencies urban buses at least four times an hour
17	Urban buses do not depart early
18	Interurban buses do not depart earlv
19	Urban and interurban buses do not deoart early

* service100 % according to the timetable.

** 50 % service according to the timetable and 50 % according to the distribution of the deviations.

In this particular case total travel time decreases by 12.5 %; this is partly caused by a decrease in waiting time. However, in other chains adverse effects on waiting times occur. On average the transfer time slightly decreases by a 10 % increase in operating speed of interurban buses.

The results for average travel time during the morning peak are presented in table 8. In the existing situation the simulated average journey time during the morning peak by public transport takes 65.9 minutes. This total travel time is split into 55.3 minutes in-vehicle time and 10.7 minutes waiting time at transfer points. The average unreliability, measured as the difference between the total travel time according to official timetables and the simulated total travel time, is 6.0 minutes. The decrease in in-vehicle time added to the decrease in waiting time are the total travel gains of each variant. The decrease in unreliability is measured in table 8 as the decrease in the difference between the average simulated travel time and the scheduled travel time (a negative sign indicates an increase). Note that the results in table 8 show the impact of each variant for public transport use in the Netherlands in general, and not merely for the chains affected by the specific variant (see *step* 2).

Table 8 Impact of reliability enhancing measures on in-vehicle time, waiting time and unreliability (in minutes compared to the existing schedules).

Variant		Decrease in-vehicle time	Decrease waiting time	Decrease unreliability
1	Bicycle used as entrance mode	-1.3	2.1	1.3
2	Bicycle used as exit mode	-1.6	34 .	1.9
3	Bicycle used as entrance and/or exit mode	-2.9	52 .	3.0
4a	Interurban buses 100 % reliable	-0.2	16 .	1.3
4b	Interurban buses 50 % reliable	-0.1	0.7	0.5
5a	Urban buses 100 % reliable	-0.2	1.1	0.8
5b	Urban buses 50 % reliable	-0.1	0.5	0.3
6a	Tram 100 % reliable	0.1	0.9	0.9
6b	Tram 50 % reliable	0	0.4	0.3
7	Increased transfer times	0	-0.5	2.5
8	Speed train increased	13 .	-0 . 1	0.1
9	Speed interurban buses increased	08 .	01 .	**0**
10	Speed all modes increased	39 .	0	0.6
11	All frequencies at least twice an hour	0	14 .	14 .
12	Train frequencies at least twice an hour	0	02 .	01 .
13	Train frequencies at least four times an hour	0	0.6	05 .
14	Frequencies interurban buses at least twice an hour	0	1.0	10 .
15	Frequencies urban buses at least twice an hour	0	0.3	02 .
16	Frequencies urban buses at least four times an hour	0	0.6	05 .
17	Urban buses do not depart early	0.4	0.3	06 .
18	Interurban buses do not depart early	0.3	05 .	0.6
19	All buses do not depart early	0.6	07 .	13 .

The impact of the use of the bicycle as an entrance and/or exit mode in public transport chains is relatively large: since bicycles are slow, their introduction leads to a substantial increase in 'in-vehicle time' (in this case it would be better to speak of 'on-vehicle time). However, due to a more reliable connection, this increase in in-vehicle time is more than compensated for by a decrease in waiting time and by a strong improvement of reliability. It is remarkable that when buses operate according to schedule the in-vehicle times increase slightly (variant 4a-5b). However, total travel times improve because of a larger decrease in waiting time. In all variants in which a mode becomes more reliable – 4a-6b - the entire transport chain becomes slightly more reliable. The improvement of getting a connection in public transport chains by increasing relatively short transfer times within the chains – variant 7 - leads to a slight increase of the average waiting time. However, this increase in waiting time is more than compensated for by a strong improvement of reliability. The increase in operation speed of modes – variants 8- 10 – leads to an improvement in total travel time caused by the improvement of the in-vehicle time. However, unless the operation speed of all modes increases by 10 %, the impact on in-vehicle time is relatively small. Also the impact on the reliability is small. This is not in accordance with our expectations. One might expect that higher operating speeds lead to an increase in transfer times (waiting times) and from that to an improvement of reliability. The improvement of frequencies – variants 11-16 - leads to a clear decrease in waiting times, particularly in the case of frequent services by interurban buses. The interurban bus services are characterised by their relatively low frequencies in the Netherlands. A twice per hour service would clearly reduce waiting times and make the system more reliable. Finally, variants 17-19 clearly show that if buses no longer depart from bus stops too early, the effects on in-vehicle time, waiting time and reliability would be favourable!

Given these effects of reliability enhancing strategies, the question now is how these strategies can be evaluated (step 8). This is the topic of the next section.

6 Evaluation of reliability enhancing strategies taking into account reliability, in-vehicle time and waiting time

In order to discover an estimation of the evaluation of reliability in transport, a questionnaire was distributed in 1997 among a sample of 781 respondents. These respondents were interviewed on their access to transport modes and their travel behaviour - both by car and by public transport- and the way they deal with road congestion and unreliability in public transport chains. Of the respondents, 29 were selected based on their model split choice for commuting and the commuting distance. The other 752 respondents were mainly participants of 'Telepanel'. Every week participants of Telepanel receive a questionnaire by computer and are obliged to respond because they have received their computers from the organiser of Telepanel. However, it appears that public transport travellers were not well-represented by Telepanel, so the organiser added a number of telephone interviews in order to correct for this omission.

Respondents were asked to indicate their preference in various choice situations. An example of a case presented to respondents is:

"Suppose you have decided to make a trip by public transport from A to B". You can choose between two alternatives (1 and 2):

Alternative 1 is characterised by the following features:

scheduled travel time:	*80 minutes,*
probability of a delay:	*0%,*
probability of getting a seat:	*100%*
price:	*dfl 12.50*

Alternative 2 is characterised by:

scheduled travel time:	*70 minutes,*
probability of delay of 1.5 minutes:	*50%*
probability of getting a seat:	*100%*
price:	*dfl 12.50*

Which of the two alternatives do you prefer?

Answer: alternative 1 or alternative 2"

If public transport travellers have a neutral attitude to risk, they prefer the second alternative because expected travel time is lower than that of alternative 1 (77.5 versus 80 minutes). In reality, most public transport travellers are rather risk-averse. An 85 % majority of the respondents prefer the certain alternative 1 above the faster but less certain alternative 2.

Based on questions of this type where the two alternatives differ according to two aspects and the remaining two aspects are identical, we have estimated the parameters of a utility function with the following arguments: in-vehicle time (measured in minutes), 50 % probability of a 15 minute delay, 25 % probability of not getting a seat, and price of ticket (measured in dfl). A well-established way of modelling this type of discrete choice data is by using the logit model (Cramer, 1991); detailed results on the estimation are presented in Bruinsma et al. (1998). The resulting values of scheduled travel time, reliability of travel time and probability of getting a seat are presented in table 9 (in guilders).

The estimated values obtained for the scheduled travel time are near to other estimations for the Netherlands (see HCG, 1998). The estimate for unreliability means that public transport travellers are prepared to pay an additional amount of df14.8 1 in order to reduce a 50 % probability of a 15 minute delay to zero. This is a rather high extra cost given the reference value for the trip of dfl 12.50.

Table 9 Estimation of valuation of travel time, reliability and probability of getting a seat in Dutch euilders

	Public Transport	Car
Reduction of scheduled travel time (per hour)	16.04	16.54
Reduction to zero of a 50 % probability of a delay of 15 minutes	4.81	4.77
Reduction to zero of a 25 % probabilitv that there is no seat	3.09	--
Reduction of scheduled in-vehicle time (per minute)	0.27	0.28
Reduction to zero of a 50 % probability of a delay of 2 minutes	0.64	0.64

In order to make the in-vehicle time and reliability estimates comparable, we have recomputed them for a standard time unit of one minute at the bottom of the table, assuming that valuations are proportional to the length of the time units concerned. The valuation of a certain in-vehicle time loss of 1 minute is 27 cents, whereas the valuation of a 50 % probability of a 2 minute delay is 64 cents. Thus, in transport an ‘uncertainty minute’ is weighed as a factor 64/27=2.4 higher than a certain minute. In the case of a risk-neutral traveller, these values would be equal. The conclusion is that respondents show a substantial dislike for unreliable transport **services.**

A similar result is found for the comfort problem that one does not get a seat. It appears that (at the range of length of trips over one hour) travellers are prepared to pay an amount of circa df13 when they can avoid a 25 % probability that there is no available seat.

An important implication of the above estimates is that when public transport operators succeed in improving reliability (small delays) and comfort (seat availability), their customers are prepared to pay more for the services. Measures to improve reliability may therefore have substantial impacts on the total receipts of public transport companies (Allen et al., 1985 present a similar view in the field of freight transport).

Table 9 also gives results for car trips. In this case of course the seat problem does not exist. The values of travel time and unreliability in car trips are of about the same order of magnitude as in public transport trips.

It is clear that an evaluation of reliability enhancing measures should not only take place on the basis of scheduled travel times, but also on the basis of the actual travel times in order to take uncertainty into account. For example, the rescheduling of trains such that the scheduled time at the interchange from one train to another is at least 10 minutes, leads to an increase in scheduled travel time, but also to an increase in reliability. Another consequence of such a policy would be that waiting on platforms would take more time.

We also pay attention to the aspect that waiting on platforms is generally considered to be less comfortable than sitting inside a public transport vehicle. Van der Waard (1989) finds that waiting time on platforms is weighed with a factor of about 1.5 compared with in-vehicle time. Our evaluation is therefore based on generalised travel time, where three components have been outlined: scheduled in-vehicle travel time (weight 1), scheduled waiting time on platforms (weight 1.5), and an uncertainty penalty for the average number of minutes above the scheduled travel time (weight 2.4).

Table 10 Impact of reliability enhancing measures on generalised travel time (zero case: existing: schedules).

Variant		Improvement in generalised: Travel time (in minutes)	Travel cost (in guilders)
1	Bicycle used as entrance mode	5.0	1.33
2	Bicycle used as exit mode	8.1	2.16
3	Bicycle used as entrance and/or exit mode	11.7	3.24
4a	Interurban buses 100 % reliable	5.3	1.43
4b	Interurban buses 50 % reliable	2.2	0.58
5a	Urban buses 100 % reliable	3.4	0.90
5b	Urban buses 50 % reliable	1.4	0.37
6a	Tram 100 % reliable	3.6	0.97
6b	Tram 50 % reliable	1.3	0.35
7	Increased transfer times	5.3	1.40
8	Speed train increased	1.4	0.37
9	Speed interurban buses increased	1.0	0.26
10	Speed all modes increased	5.3	1.44
11	All frequencies at least twice an hour	5.5	1.46
12	Train frequencies at least twice an hour	0.5	0.15
13	Train frequencies at least four times an hour	21 .	0.56
14	Frequencies interurban buses at least twice an hour	39 .	1.05
15	Frequencies urban buses at least twice an hour	09 .	0.25
16	Frequencies urban buses at least four times an hour	21 .	0.56
17	Urban buses do not depart early	23 .	0.61
18	Interurban buses do not depart early	25 .	0.66
19	All buses do not depart early	48 .	1.28

The results of this exercise – in minutes and Dutch guilders - are given in table 10 (see table 8 for the changes in in-vehicle time, waiting time and uncertainty). In particular, due to the strong improvement in the reliability of public transport chains, the average passenger gains most when bicycles are used as an entrance and/or exit mode. Other measures which are relatively inexpensive to implement and result in relatively large gains for the average public transport passenger are an increase in transfer times and a strict constraint on bus drivers to prevent them from departing early. The first measure leads to an increase of slack in the system, thus implying longer waiting times but higher reliability; the second measure can be achieved by accurate route planning and instructions for bus drivers. Other measures that result in reasonable gains for the average public transport passenger are to increase the average speed of all public transport modes and to increase the frequencies of public transport services, particularly the frequency of interurban buses.

The figures in table 10 all relate to generalised travel time of the average ***passenger.*** The costs of the ***transport operators*** are not regarded. We also did not consider the difference in comfort between using public transport and using the bicycle as an entrance or exit mode. Since the costs of the operator are not included, the figure does not give the ultimate answer as to which strategy is best. It is clear, however, that the contents of this table provide an important piece of information for a broader analysis. They also indicate a likely acceptance of an increase in public transport tariffs if reliability is improved.

7 Conclusions

Unreliability in public transport means that actual departure and arrival times may deviate from the official timetable. Data on unreliability are usually uni-modal. In this paper we have addressed unreliability from a multimodal perspective. This means that explicit attention has been paid to the probability that one misses a connection between elements of a chain. This also implies a shift of attention away from the supplier towards the customer.

Estimates of unreliability of public transport chains in the Netherlands are provided. The density of arrival times is peaked around zero, but it has some additional peaks at delays of 30, 60 and 120 minutes. This relates to the basic frequencies of most public transport services in the Netherlands. Thus, frequencies of public transport services appear to strongly influence the overall distribution of arrival times of passengers.

We found that the average delay of public transport chains is rather small: about 6 minutes, given an average length of circa 1 hour. The reason is that a substantial part of all trips (about 30 %) arrive (slightly) early. The probability of an on time arrival or a short delay between 0 and 5 minutes is estimated at about 45 %. Very long delays (more than 30 minutes occur in about 5 % of the cases). On Sundays the reliability of individual elements of chains is higher than on weekdays, but due to low frequencies the probability of long delays is also higher.

Customer valuation of unreliability is estimated by means of a stated preference approach. We found that the valuation of a certain in-vehicle travel time loss of 1 minute is 27 cents, whereas the valuation of a 50 % probability of a 2 minute delay is 64 cents. This implies a strong risk-averse attitude towards travel time by most passengers. Waiting time on platforms is valuated by a factor of about 1.5 compared with in-vehicle time. On the basis of these values, an evaluation of reliability enhancing strategies has been carried out. We conclude that among the most promising means of improving the overall quality of the chains is that the traveller use the bicycle as an entrance and exit mode. Other measures which are relatively inexpensive to implement and result in fairly large gains for the average passenger are an increase in transfer times and a strict constraint on bus drivers to prevent them from departing early.

The result for the importance of the bicycle as a transport mode in public transport chains implies that public transport operators should pay attention to issues such as good parking facilities near public transport stops (railway stations) and improve measures to prevent theft. A major obstacle against the use of bicycles in the Netherlands is the perceived probability of theft by potential bicycle users. Another item might be to increase the-possibility of keeping the bicycle on public transport trips. It allows passengers to use their bicycle as an entrance and exit mode and solves the problem of theft.

The approach to an unreliability analysis carried out in our paper can be further developed. Of special importance is the inclusion of behavioural elements of public transport drivers and/or traffic control, such as adjusting speed or length of stops in the event of delays, and waiting for delayed vehicles to ensure that transfer passengers do not miss their connections. Another important direction for further research is the inclusion of interdependencies of disturbances in the system due to overall exogenous conditions.

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Endnotes

1. The difference between the two perspectives in the case of chains with only one element is that vehicles may be rather empty towards the end of a line, therefore drivers have an opportunity to drive faster (or have fewer stops) so they can partly compensate for delays during the middle part of the service they provide. Therefore, there may be a tendency that reliability statistics indicating the percentage of vehicles arriving on time at the end of a line understate the problem of unreliability as experienced by the majority of passengers using the line.

2. Note that the data in this table indeed suffer from the problem mentioned in note 1 that reliability only relates to arrival times of trains at endpoints; intermediate stops are neglected.

3. If the data consisted of the individual realisations of arrival times, there would be no need to estimate a distribution function. In that case the simulation study could have been conducted by taking a sample from the observed distribution.

4. We assume that speeds are increased without changing the distributions of differences between actual and scheduled departure and arrival times. We ignore the potential adverse effects of higher speeds on reliability of the services concerned. The major effects of a speed increase are shorter travel time (based on the last element in the chain) and longer waiting times, plus a higher probability that a connection is realised at a public transfer point for the other parts of a chain. Conversely, higher speeds in the earlier part of a chain may occasionally mean that waiting time is reduced because an earlier connection becomes feasible.

5. The relatively high number of buses that depart early from bus stops may be due to a lack of discipline of bus drivers combined with ignorance about reliability issues by bus company managers. However, a different explanation might be that bus drivers anticipate on tightly-planned parts of the bus schedule by leaving early from parts of the schedule where there is slack. If, in the latter case, bus drivers were prevented from leaving early at certain parts of the schedule, delays at other parts of the schedule would increase. In the simulation we did not take into account this possibility.